by projection on a cardboard screen, on a scale of 12 inches for the diameter of the image of the Sun.

Owing to a dense fog contacts I and II could not be observed, the Sun remaining obscured until 10 o'clock.

The observations of contacts III and IV were as follows :

III.	1^h	11^m	23^s	P. S. T.
IV.	1	13	2	

The seeing was fairly good. The time was noted by Mr. F. H. McCONNELL, who received the correct time at noon, direct from the LICK Observatory. Very truly yours,

F. R. ZIEL.

SAN FRANCISCO, November 10, 1894.

CONCERNING AN ATMOSPHERE ON *MARS*.*

BY W. W. CAMPBELL.

In forming an estimate of the extent of the atmosphere surrounding the planet *Mars*, a great many classes of observed phenomena must be considered. I shall try, in the following pages, to bring together and to discuss very briefly the most important facts bearing upon this question.

(1) *The Small Mass of the Planet.*—It is reasonable to suppose that the mass of the atmosphere surrounding a planet is roughly proportional to the mass of the planet itself. The largest planets would have the most extensive atmospheres. This rule actually appears to hold good. There is no evidence of an atmosphere on our Moon, nor on any of the satellites in the solar system. There is substantially no evidence of an atmosphere on the small planet *Mercury*, but there are unmistakable evidences of extensive atmospheres on the large planets *Jupiter*, *Saturn*, *Uranus* and *Neptune*, compared with which our own atmosphere is very slight.

Now, the mass of *Mars* is only 0.11 that of the Earth. The area of the surface is 0.28 that of the Earth. If the atmospheres of the two planets are proportional to their masses the quantity

* This question relates simply to the *extent* and *character* of the Martian atmosphere. Whether or not an atmosphere of any given extent and character will support life is quite outside of the astronomer's province.

of air above a square mile on *Mars** would be only 0.39 of the atmosphere above a square mile on the Earth.

(2) *The Color of the Planet.*—Many observers consider that the reddish-orange color of *Mars* is caused by the action of its atmosphere, in absorbing the rays at the violet end of the spectrum more strongly than it does those at the red end. It has even been said that the Earth would probably exhibit the same tint if it could be seen from without. The red color of the Sun near sunset, and the copper color of the Moon when near the horizon, are well-known instances of the strong absorption of the blue and violet rays by the thick stratum of atmosphere through which their light must travel. From recent comparisons of the colors of *Mars* as seen in the telescope and of the Moon as seen near the horizon by naked eye, I estimated that the colors of the two bodies approached most nearly to equality when the planet was on the meridian at altitude 60° and when the Moon was from 3° to 5° above the horizon.† At those altitudes the lunar light traversed paths in our atmosphere from nine to sixteen times as long as that traversed by the light from *Mars*. That is, if the orange hue of *Mars* is caused by an atmosphere similar to our own, it must be many times as extensive as our own. Some of the sunlight reflected to us by the planet has passed twice through its atmosphere, but much of it would pass only partially through before being reflected. It would seem, therefore, that this explanation of the red color of the planet would require an atmosphere from six to twelve times as extensive‡ as our own.

We shall see, later on, that all the other observed phenomena are opposed to that theory. In this section I shall mention only three:

First.—The edge of the disc is always *whiter* than the centre. This is an easy observation to make, and the fact has been recorded by many observers. Among others, it was noticed by

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* The density of the atmosphere at the surface of *Mars* is also of interest. The force of gravity at the surface of *Mars* is only 0.38 of the force of gravity at the Earth's surface, and the density of the atmosphere at *Mars'* surface would be only 0.15 as great as at the Earth's surface. That is, less than one-half the density of our atmosphere at the summit of the Himalaya Mountains.

† This estimate is of course only roughly approximate. The observation should be made by a reflector, which is free from chromatic aberration. The light from *Mars*, also, appears to have a distinctive tint which cannot be exactly matched by lunar light.

‡ By this I mean that above any given area on *Mars* (a square mile, for instance), there would have to be from six to twelve times as many molecules of atmosphere as there are above an equal area on the Earth.

DAWES, who wrote in 1864: "Nothing, as it appears to me, can more fully prove that the ruddy tint of *Mars* does not arise from any peculiarity in the color of the planet's atmosphere, than the fact that the redness is always deepest near the centre, where the atmospheric stratum is thinnest." In other words, if the redness at the centre is produced by the atmosphere, the greater thickness of the atmosphere at the edge should cause *increased* redness. Observation shows that exactly the contrary is true.

Second.—There is no evidence of absorption by the atmosphere over the polar caps. I think all observers have assigned to them a pure snow-white color, even at the edge of the planet. If the red color at the centre of the planet were due to atmospheric absorption, the absorption at the edge of the disc would be enormously greater, and the polar caps would not be pure white. They would incline to the yellow or red, very much as the rest of the planet does.

Third.—The spectra of the large planets *Jupiter*, *Saturn*, *Uranus* and *Neptune* contain prominent atmospheric bands, showing unmistakably that those planets are surrounded by extensive atmospheres. In *Mars* the spectroscopic evidence, as we shall see in the following section, is, to say the least, extremely slight. Yet *Mars* is vastly redder than the four outer planets. The spectroscopic evidence is therefore undeniably against the theory that the red color of *Mars* is caused by an extensive atmosphere.

In view of the facts that the limb of the planet is *whiter* than the central regions, that the white polar caps present no evidence of absorption even at the very edge of the disc, and that the larger planets with more extensive atmospheres than *Mars* are whiter than *Mars*—in view of those facts we must accept as satisfactory the explanation offered by Sir JOHN HERSCHEL half a century ago, that the red color "indicates, no doubt, an ochrey tinge in the general soil, like what the red sandstone districts on the Earth may possibly offer to the inhabitants of *Mars*, only more decided."

(3) *Spectroscopic Results.*—An account of the spectroscopic observations of *Mars* is contained in No. 37 of these *Publications* and the reader is referred to that paper for details. In brief, the investigations of JANSSEN about 1867, HUGGINS in 1867, SECCHI about 1872, VOGEL in 1872, and MAUNDER in 1877, led them to

substantially the same result, viz: *The atmosphere of Mars is similar to our own.* It must be noticed that none of the observers, so far as I know, formed from their spectroscopic evidence any estimate of the *extent* of the Martian atmosphere as compared with our own. One of the observers stated that the critical lines and bands were stronger in the planet's spectrum than in the lunar spectrum when these objects were at the same altitude above the horizon; another stated that the critical bands were broader in *Mars*' spectrum than in the Moon's, and another observer did not see the critical lines in the lunar spectrum at all, but did see them in the planet's spectrum. Now, if the atmosphere of *Mars* is similar to our own, and if at the same altitude the critical lines are stronger in the planet's spectrum than in the Moon's, there ought to be some *lower* altitude of the Moon such that the critical lines would be of equal strength. By this method—and by no other spectroscopic method, so far as I know—an estimate of the extent of the Martian atmosphere can be formed. It likewise would afford a test of the delicacy of the spectroscopic method. None of the observers seem to have sought for those (unequal) altitudes of *Mars* and the Moon for which the critical lines in the two spectra would be of equal intensity. It is unfortunate that this was not done.

It should also be noted that the observers found no certain evidence of increased absorption at the edge of *Mars*, where the thickness of atmosphere would be greatest.

The spectroscopic observations made at Mount Hamilton this summer, under especially favorable circumstances, showed that the spectra of the Moon and *Mars* were apparently identical, and that the method was sufficiently sensitive to have shown the existence of a possible Martian atmosphere about one-fourth as extensive as our own.

Thus the early observations of the spectrum of *Mars* gave some evidence of an atmosphere, but none of the observers have given us an estimate of its extent. The recent observations gave no evidence of an atmosphere, and were apparently able to detect an atmosphere if it were one-fourth as extensive as our own.

(4) *Distinctness of Surface Markings.*—If *Mars* were surrounded by an atmosphere as extensive as our own it is hardly possible we should see the surface features as clearly as we do. LANGLEY found that about 40 per cent. of the light coming to the Earth's surface from a celestial object near the zenith is

absorbed by our atmosphere. If the reflecting power of the Earth's surface is equal to that of the Moon, which is about 0.17, then of the 60 per cent. of the original light reaching the Earth's crust, only 0.17, or ten parts of the original hundred, would be reflected, and about 40 per cent. of this would be absorbed in passing out through our atmosphere. That is, only about 6 per cent. of the light originally striking the Earth's atmosphere would both reach and pass out directly from the Earth's crust. The surface would, however, be illuminated by the diffused sky light, and the light passing out from the surface to surrounding space could perhaps be estimated at 9 or 10 per cent. The light by which a distant observer, say on *Mars*, would view the Earth, would come very largely from the bright atmosphere and only very slightly from the real surface of the Earth. It is doubtful whether any of the Earth's surface features would be seen at all, even were our sky clear from clouds.

It has been urged that the *indistinctness* of the surface markings at the edge of *Mars* is due to the fact that we are there looking through great depths of atmosphere. I do not think this assumption is necessary. If we examine the lunar surface by naked eye we shall find that the markings are distinct at the centre, but become indistinct at the border. The Moon by naked eye is comparable in size with *Mars* as seen in a telescope. If we make allowance for the highly magnified effect of poor seeing in examining the blurred and indistinct edge of *Mars*, we shall find, I believe, that the edge of *Mars* is not greatly more indistinct than is the edge of the Moon. That the markings cannot be followed even up to the edge of the Moon and *Mars* is due mostly to foreshortening.

(5) *The Polar Caps.*—The excessive brightness of the polar caps, as compared with the central areas, at once renders the theory of a thick atmosphere untenable. If there *were* a thick atmosphere it would be extremely thick at the edge, where the polar caps are. Comparatively few of the Sun's rays would penetrate far enough to strike the material composing the caps. Those which did strike the caps would be largely reflected; but very few of these rays, in turn, would succeed in getting back through the thick atmosphere. Those portions of the polar caps nearest the edge of the disc would not have their present excessive brightness. This brightness can be explained only on the supposition that the planet's atmosphere is very thin.

The waxing and waning of the polar caps with the winters and summers on *Mars*, combined with their white color, have led most observers to suppose that they are composed of snow and ice. This view suggests at once that *Mars* has an atmosphere containing aqueous vapor. The caps are certainly analogous to the Earth's polar caps, so far as their waxing and waning and white color are concerned; but the analogy really extends no further.

An observer on the Moon or on *Mars*, looking at the Earth, would be hindered in his observations not only by our atmosphere, but by our clouds. The hemisphere turned toward him would never be wholly clear. We know that at times practically the whole of the central and eastern portions of North America are covered with clouds which at the same time extend far out to sea. To an outsider the cloud areas would be brighter than the clear areas. The contrast between clouded and clear regions would be greater than between land and water. We are by no means certain that our permanent boundary lines of land and water would be visible to an outsider, even in clear weather, on account of the much brighter sky covering them; but let us suppose them to be. They certainly would be complicated and lost in our cloudy weather. It is probable that our polar regions are enveloped in clouds more than half the time; in the temperate zone the proportion is less than one-half; while in certain equatorial regions there is almost perpetual cloudiness.

The conditions on *Mars* are very different. We are not justified in holding that clouds have ever been seen on that planet. The polar caps wax and wane. If the caps are composed of snow, when they are melting we would expect to see clouds in the polar regions. We have absolutely no evidence that clouds ever appear there. On the contrary, there is conclusive evidence that the margins of the polar cap are clear of clouds for at least weeks and months. I refer to the evidence of the bright projections jutting out from the edge of the polar cap upon the adjacent darker regions of the disc. These projections and the similar detached portions of the cap, remain constantly visible for weeks with substantially no change of form, and no change in definiteness of outline. Similarly there is no conclusive, or even strong, evidence that clouds ever form in the equatorial regions of *Mars*. To a distant observer the evidence of clouds on the Earth must be unmistakable. So

far as we know, the Martian inhabitant is not aware that a cloud can exist! If the conditions of our own atmosphere are good, the principal contour lines on *Mars* are always visible. When we begin observations for the night we do not ask : Is *Mars* clear to-night? but always : Is our own atmosphere tranquil? We do not stop work because *Mars* has clouded over, but because our own atmosphere is cloudy. *Mars* appears to be always clear.

The conclusion to be drawn from this is, that since there is no evidence of clouds there is no evidence from the polar caps that aqueous vapor* exists in an atmosphere, or that any circulation of the materials forming the polar caps takes place in an atmosphere.

There is another important piece of evidence which must not be overlooked. The planet *Mars* is much further from the Sun than we are. The intensity of the Sun's heat and light are only three-sevenths as great on *Mars* as on the Earth; and yet its climate *seems* to be milder than our own. Not only do the polar caps in the winters not extend so near the equator as they do on the Earth, but they sometimes disappear entirely under the influence of the summer sun. The south polar cap disappeared entirely about the middle of last October. It would be an easy matter, apparently, for an arctic explorer to reach the poles of *Mars*. While this condition of things can possibly be explained by the fact that their summers are very long, we must not forget that their winters are also very long, and the accumulation of snow during their winters should be correspondingly great. If the polar caps are snow, we must consider that the Martian climate is milder than our own. But, on that basis, how can we explain the absence of clouds?

Several observers have pointed out that the polar caps may consist of frozen crystals of carbonic acid. This theory† has

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* In concluding my paper on "The Spectrum of *Mars*," *Publications* A. S. P., page 236, I said that "While I believe that the polar caps on *Mars* are conclusive evidence of an atmosphere and aqueous vapor, I do not consider that they exist in sufficient quantity to be detected by the spectroscope." I now think that the expression "conclusive evidence of an atmosphere and aqueous vapor" is too strong. In making the spectroscopic observations I was constantly holding in mind the idea that the polar caps *were* snow, that the spectrum *ought* to show the aqueous vapor lines, and in the beginning I had expected to find it an easy matter to *confirm* the old observations. It is difficult to give up ideas once firmly held.

† Professor HOLDEN and other astronomers have often remarked that while analogy suggests the theory that the polar caps are snow, there are other substances whose properties are such that they may possibly satisfy the existing conditions better than snow does. One of our members, Mr. HENRY H. BATES, has written an interesting and suggestive letter on the carbonic acid theory of the caps. His letter is published on another page of these *Publications*.

much in its favor. Carbonic acid may be both liquefied and frozen when subjected to intense cold. It may be frozen into a transparent ice-like mass, or into white snow-like flakes. The white flakes would retain their form and color so long as the temperature was lower than 109° below zero Fahrenheit! When the temperature would rise above — 109° the white flakes would be transformed into a colorless vapor. If the caps were composed of the white flakes of carbonic acid, they would wax and wane under the influence of the Sun's heat just as they are observed to do. We would be relieved from the necessity of considering that *Mars* has a milder climate than the Earth has. The absence of clouds would be explained. The absence of spectroscopic evidence of atmosphere and aqueous vapor would be explained. The clearness of view and the white color of the polar caps would be explained. Carbonic acid gas is a prominent constituent of our atmosphere, and it is not unreasonable to suppose that it exists abundantly also on *Mars*. It may even be the principal constituent of *Mars*' atmosphere. The late Dr. STONEY has elaborated an ingenious theory to account for the absence of atmosphere on the Moon, and in fact to explain how any small planet may gradually lose its atmosphere. His theory is based upon the accepted dynamical theory of gases. According to the dynamical theory of gases, all the atoms or molecules making up a gas are in constant and violent motion. The little particles fly with tremendous speed, in some cases exceeding the velocity of rifle balls. If there were no resisting force the particles would fly on and on, and the gas would be almost instantly dissipated and lost. In the case of a planet's atmosphere, the force of gravity is the force which overcomes the velocities of the particles and keeps them from flying off into space. The large planets attract their atmospheres more strongly than the small planets do, and the heavy gases are more strongly attracted than are the lighter gases. Dr. STONEY considered that the maximum velocities of the atoms of hydrogen, nitrogen and oxygen are so great, that if these gases ever existed on the Moon the gravity of the Moon would be too small to overcome those velocities. The particles would, one by one, fly off into outer space, never to return. He considered the fact that the Moon has no appreciable atmosphere could be accounted for in that way. Now, hydrogen is the lightest of the gases and its atoms fly about with greater velocity than the atoms of any of the other gases. Dr.

STONEY considered that if free hydrogen existed in our atmosphere the attraction of the Earth upon it would not be sufficient to hold it. The free hydrogen would, atom by atom, fly away into outer space. He considered that our oxygen and nitrogen were too heavy to escape. Now, *Mars* is intermediate in mass between the Earth and Moon. If all of the constituents of the Moon's atmosphere could escape its attraction, and if free hydrogen could escape the Earth's attraction, it is probable that all but the heavier gases on *Mars* could escape the attraction of that planet. Now, in our atmosphere it happens that water vapor is the lightest; the combined nitrogen and oxygen come next in weight; and the carbonic acid gas is the heaviest of all. There might come a time on *Mars*—the present time, for instance—when the carbonic acid constituted the greater part of its atmosphere. If such were the case, the temperature of the surface of the planet would probably be very low, low enough to freeze the carbonic acid into snow-like flakes. [It is for physicists, rather than for astronomers, to decide upon the merits of Dr. STONEY'S theory. See Sir ROBERT BALL'S interesting account of this theory in *Publications* A. S. P., Vol. V, pages 25–29.]

But it is not necessary that we send the atmosphere of *Mars* out into space. It might easily go in exactly the opposite direction. That planet is much smaller than the Earth. It is probably older than the Earth, but we do not know it is. At any rate, being smaller, it would cool off in a small fraction of the time required by the Earth. It has probably gone far beyond the present condition of the Earth. As a planet grows older it is but natural that more and more of the oxygen in its atmosphere should be taken up by the constituents of its crust. It is pretty certain that more and more of our oxygen is taken up by the iron and other elements in the Earth's crust to form the oxides of those elements. It is possible that other elements of our atmosphere are gradually passing into the Earth's crust. Possibly the carbonic acid is left behind and in that way is becoming relatively more plentiful. Possibly processes similar to these have been going on in the atmosphere of *Mars*. Thus, if *Mars* originally had an extensive atmosphere, only a small residue of it might now remain, and its character might have become radically changed. It is possible, too, that other elements of the Martian atmosphere may assume the snow-like form and color under the influence of extreme cold. The view that the polar

caps consist of snow, and are therefore evidence of aqueous vapor in the atmosphere, leads us into great difficulties. Moreover, that view of their composition is not *necessary*. The caps may consist of carbonic acid, or of some other substance very different from our snow. [Considerable space has been given to the carbonic acid theory in this paper, not because the writer accepts that theory, but only for the purpose of calling attention to the fact that we are not limited to the one theory that the caps consist of snow and ice.]

It is not unreasonable to suppose that the characters of the Martian and terrestrial atmospheres may be very different. The planets are passing through processes of evolution covering millions of years. *Mars* and the Earth differ in mass and distance from the Sun. The probability that at the present time the conditions on *Mars* are approximately the same as those on the Earth is very slight indeed.

(6). In many respects *Mars* resembles the Moon, which has no appreciable atmosphere. First, the reflecting power of the surface of *Mars* is very small. It is but little larger than that of our Moon, or than that of *Mercury*, which presents no certain or strong evidence of an atmosphere. It is very much less than for the four large planets on which we know there are very heavy atmospheres. Second, the edge of *Mars* is much brighter than the inner portions of the disc, just as on the Moon, and probably for the same reasons, viz: The mountain surfaces on the two bodies reflect light more strongly than do the plains. The reflecting surface at the centre of the disc in each case is composed of both mountains and plains; while at the edge of the disc the reflecting surface is composed almost wholly of mountains, since the valleys have passed out of sight. That the increased brightness is due to surface features and not to atmosphere is shown by the fact that the brightening at the edge of *Mars* is not uniform, and neither is it on the Moon. Then, too, on those planets which we know are surrounded by an extensive atmosphere, *Jupiter* and *Saturn* for instance, the edges are actually much *fainter* than the centres of the disc are.

ZÖLLNER has estimated that if the greater brightness at the edge of *Mars* is due to mountains, they must be exceedingly steep —that their slopes must make an angle of 76° with the horizon. I have no hesitation in expressing the opinion that ZÖLLNER's estimate is excessive. I do not think the edge of *Mars* is

relatively brighter than the edge of the Moon, and do not think that excessively steep slopes are required. Some of the apparent brightness of *Mars* is unreal, and due to contrast with the dark sky background,* as Professor ORMOND STONE and others have pointed out; and some of it is real, and probably due to the greater reflecting power of the mountainous areas making up the visible edge of *Mars*.

(7). At the last three oppositions of *Mars*, we have observed bright projections jutting out from the terminator of the planet. These projections were probably high mountain peaks.† If they were mountains, they could not possibly have been seen if they had been placed at the bottom of a thick atmosphere. Either the projections are not mountains or the atmosphere is thin.

There are light and dark areas on *Mars*. If we make proper allowance for the high magnifying power used on *Mars*, the contrasts between the light and dark shades on that planet seem to be about the same as the contrasts between the light and dark regions on the Moon. The light and dark regions on the Moon are both land. Most astronomers hold that the bright markings on *Mars* are land and that the dark markings are water; but several astronomers hold exactly the opposite view. Since there is very slight, if any, evidence of aqueous vapor or clouds on *Mars*, it seems to me that there can be no fatal objection to the working hypothesis that both bright and dark markings may for the *most* part be land.

It may be true that changes are going on from time to time in the outlines of the so-called continents and so-called canals. One must systematically observe the planet at a great many oppositions if he wishes to give an opinion of any value on that subject. However, the longer I observe the planet, the stronger becomes the opinion that the varying conditions of our own atmosphere and the different distances and positions of the planet are responsible for most, if not all, of the differences between the drawings made by an observer at different times.

In conclusion, it seems to me that so far as the atmosphere of the planet is concerned, the conditions approach more nearly those existing upon the Moon than those existing upon the Earth.

MOUNT HAMILTON, November, 1894.

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* This is shown conclusively to be the case by making the observations after sunrise, when the sky background is bright.

† For the history of this subject, see *Publications* A. S. P. for 1894, pages 103-112.